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NATIONAL FOREIGN ASSESSMENT CENTER
CENTRAL INTELLIGENCE AGENCY
Washington, D.C.

24 June 1980

MEMORANDUM FOR: John Boidock
Chairman
Technical Working Group 5
Institute for Defense Analyses

SUBJECT : Critical Technologies: Semiconductor
Equipment and Materials

1. Attached is a discussion of the capabilities of the USSR and East European countries to manufacture semiconductor production equipment and materials. The attachment follows the format of your request.

2. I call your attention to the classification and special controls on the attachment. [redacted]

[redacted]

[redacted]
Office of Economic Research

Attachment:
As Stated Above

ERM-80-10375

COORDINATION NOT DEEMED NECESSARY

DERIVATIVE C/D BY [redacted]
C/DECL & REVW ON June 30, 1980
DERIVED FROM Multiple

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Microcircuit Fabrication: Manufacturing
Equipment and Materials

1. During the past five years the USSR has made important gains in production and state-of-the-art of microcircuits. Progress has been fastest in the areas of design and fabrication, slowest in the development of equipment for manufacturing and testing, and in the installation of production capacity for materials. To a major extent Soviet progress was made possible by the successful acquisition of impressive amounts of Western materials covering most of the material inputs, and of manufacturing and test equipment for nearly every manufacturing process. The Soviets remain significantly dependent upon the West for manufacturing technology and are likely to remain dependent well into the 1980s. ☐

2. In Eastern Europe only East Germany appears to have mounted a major effort to develop production equipment for advanced microcircuits. Developments of major significance include mask-making and lithography equipment and electron beam technology for thin film deposition. In these areas, East Germany is more advanced than the USSR. East Germany has indicated plans for a major expansion of silicon production capacity, possibly to serve Soviet needs since recent evidence indicates that the Soviets have been pressuring East Germany to assume a larger role in supporting the Soviet semiconductor industry. ☐

3. Generally, progress in microcircuit technology in the USSR and Eastern Europe is unbalanced. Many gaps persist over the full range of microcircuit manufacturing materials and equipment, which are not filled by the USSR or any other CEMA country. These gaps can be expected to soon increase the need for Western material and equipment as the USSR is about to enter large scale production of LSI devices. ☐

4. It follows that an effective embargo on microcircuit fabrication equipment and materials to the USSR and Eastern Europe would have a powerful impact by slowing Soviet progress in semiconductor technology. ☐

Wafer Preparation

5. The USSR has the basic know-how to perform all the major processing steps of wafer preparation from crystal growth through inspection. Most of the equipment for these processes is believed

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to be Western-made. The Soviets also make equipment for these purposes, but of generally lesser capacity and sophistication. ☐

6. Of the three basic substrate materials for micro-circuits--silicon, sapphire, and gallium compounds--the USSR has only silicon in full production. Gallium compounds are produced in small quantities. Sapphire is in an advanced development stage. ☐

Silicon

7. The USSR currently produces between 100 and 200 tons per year of polysilicon (we assume that Soviet polysilicon is produced from trichlorosilane or silane as is commonly done in the West). This quantity apparently is insufficient to meet domestic requirements as the USSR purchases an additional 100 metric tons of polysilicon per year from Western suppliers.* Soviet officials have indicated that large foreign purchases of polysilicon will be required through at least 1982. ☐

Monosilicon

8. The Soviets produce monocrystalline silicon based on both Czochralski and Float-zone techniques, using mostly Western-made furnaces. Soviet-made furnaces are obsolete, and there does not appear to be a strong effort to develop higher capacity, or more automated versions. The Soviets have under development ribbon silicon, or a square ingot growth process for microcircuit grade substrates. ☐

9. Since 1973, the Soviets have purchased a large number of furnaces: about 60 Czochralski models, and at least 30 Float-zone models based on information currently available. In addition, the USSR continues to purchase increasingly larger quantities of single crystal silicon ingot and wafers; in 1979, purchases of silicon ingot exceeded 10 metric tons, and wafer purchases probably exceeded 2.5 million units. Most of the silicon wafers are in the 2½" to 3" diameter sizes. It seems likely that at least half of Soviet annual output of micro-circuits is based on imported silicon. ☐

* In the late 1970s the USSR was seeking to purchase a turnkey plant in the West with an annual capacity of 400 metric tons of polysilicon per year. It is not known if a supplier was found, or if a deal was made. ☐

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10. Little information is available on Soviet techniques for measuring single crystal silicon parameters (or orientation) or on Soviet purchases of Western equipment to perform these measurements. The Soviets requested price quotes from a Western firm in mid-1979 for X-ray crystallography equipment, but it is not known whether any actual sales were made. In the ingot slicing area, the Soviets are known to have purchased in recent years up to 155 slicers of various types, and large numbers of replacement saws. ☐

11. For lapping and polishing, the Soviets produce some equipment, and purchase some from Western firms. Known Soviet purchases include eight lapping machines and 20 polishing machines for mechanical polishing of wafers. In addition, the Soviets have purchased 12 systems for cleaning of wafers after lap and polish steps. Recently, the Soviets began to switch to chemical polishing, a switch apparently that has been facilitated by the purchase of Western equipment. ☐

12. Only three countries in Eastern Europe produce silicon in significant quantities: East Germany, Poland and Czechoslovakia. East Germany hopes to raise production capacity from the current level of about 20 metric tons of polysilicon per year to 50 tons by 1983, and 100 tons by 1985, and to become a net exporter in the process. The East Germans recently claimed that they would accept orders for 75mm diameter wafers in 1980 with up to 250,000 units available for export. ☐

13. Czechoslovakia now produces 20-23 metric tons of polysilicon per year and plans to raise production to 28 tons in the near future. Poland has a capacity of 15 tons per year, represented by a polysilicon production plant acquired from West Germany. Total production of polysilicon in Eastern Europe at best does not exceed 60 tons per year. As with the USSR, East European production is largely based on Western equipment for all stages of wafer preparation. ☐

Epitaxy

14. Soviet bipolar integrated circuit (IC) production and recent samples of Soviet ECL devices employing a patterned buried layer prior to epi growth demonstrate the Soviets' good understanding and control of epi processes. However, very little is known about Soviet epi process equipment of recent vintage. In the early 1970s, Soviet epi equipment was described

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as very poor and was frequently down for repairs. One model, the "Volga", was considered unsafe for operators and was known on occasion to catch fire. In 1978, the Soviets published a technical brochure on a dual reactor system, the UNES-2PK-A, used for both liquid and gaseous dopant sources. Safety was an important consideration in design, and it includes special safety features not discussed for earlier models. The availability of the UNES-2PK-A is now known.

15. There has been very little evidence of Soviet purchases of Western epi equipment. 1/ Most of the equipment identified have been MBE systems and III-V reactors. In only one case, in early 1979, has a known purchase specified a silicon epi system.

16. In the USSR, the IC production process is divided among different plant sites. One or more plants specialize in the process from ingot slice through epi. This division of labor permits a fuller utilization of limited amounts of available equipment, and allows each facility to concentrate on a narrow part of the total production process. Although this approach has worked for ICs up to MSI complexity, it is not very workable with LSI parts and will require considerable expansion of existing epi capacity as the product-mix shifts increasingly to more advanced microcircuits.

17. Other trends which will probably result in increased Soviet need for additional and more advanced epi systems are the use of epi layers for MOS devices and the recent Soviet development of both schottky T²L and I²L technologies. Finally, as the Soviets switch increasingly to patterned buried layer diffusion prior to epi, the separation of the epi process from subsequent process steps at different physical locations will become increasingly more difficult because of tighter design rules and process control requirements. This also will generate a need for more epi equipment at individual facilities.

1/ This may be explained, in part, by substantial Soviet purchases of silicon wafers with an epi layer. However, this is not fully confirmable

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18. Except for East Germany, none of the East European countries are known to export epi systems. Most are believed to build custom in-house systems, or purchase foreign equipment. East Germany developed its first epi system in 1966, and since 1970 has claimed availability of epi systems for export. In the mid-1970s, a Western firm reviewed East German semiconductor production equipment for possible sale in the West and found that none of the equipment would be marketable in the West. It is not known if the list of equipment included epi systems, although at least two models, the EA 1 and EA 2, were available at the time. A more advanced East German epi system designated the HEA 33/1 - 33/2 is now available. This model appears very similar to the Soviet UNES-2PK-A, although technical data are insufficient for a complete comparison. Neither model is described as being a radiant heated, rotating barrel reactor.

19. The Soviets will need advanced epi reactor systems for future advances in both bipolar and MOS technology. Current Soviet and East German epi reactors, which are adequate for conventional epi growth of silicon on silicon substrates, will not suffice. Even if newer models of Soviet and East Germany equipment are sufficiently advanced to support future developments--and that is a big question mark--it is doubtful that enough epi reactors can be produced to supply total Soviet and East German needs. The possibility is strong that the USSR will attempt to purchase advanced epi reactors covertly from the West.

Oxidation

20. Conventional oxidation processes (atmosphere up to 10⁵ Pascals) are believed to be common practice in Soviet microcircuit fabrication. The Soviets use their own diffusion furnaces (resistively-heated) as well as foreign furnaces for oxidation. Little is known about Soviet use of high-pressure (10⁶ Pascals) processes, or about the availability of domestically-made equipment for such processes. Probably, such processes are not in use. It was recently learned that the Soviets have requested price and delivery information on a Western high pressure oxidation system and may purchase three complete systems. Since the importance of high pressure oxidation is only now becoming widely known and understood at the industrial level within the USSR, it is likely that efforts to acquire equipment for these processes will increase over the next several years.

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21. There is no evidence that any of the Eastern European countries have developed or have purchased high pressure oxidation systems. []

Maskmaking

22. Maskmaking equipment and technology are major weakness in Soviet microelectronics technology. To date, Soviet progress in circuit complexity has been dependent, crucially, on Soviet acquisition of Western maskmaking equipment. For example, the first Soviet LSI devices were produced only after the Soviets successfully acquired Western photorepeaters. The Soviets have attempted, urgently, to copy Western maskmaking equipment, but no copy has yet successfully duplicated the full performance capabilities of the Western model. []

23. There are indications that the Soviets may have assigned East Germany major responsibility for development and production of advanced maskmaking equipment, probably because East Germany is making faster progress in this area than the USSR. []

24. East Germany claims to have developed two types of equipment which represent advanced state-of-the-art in mask-making--a wafer stepper, ^{1/} and an E-beam mask generator. The E-beam generator, designated the ZBA-10 (built by Zeiss Jena), is a variable shaped beam system for generating mask reticles, with line widths down to 0.2 μm at accuracy levels of $\pm 0.05 \mu\text{m}$. Eventually, the ZBA-10 is to be modified for direct wafer exposure. The ZBA-10 is intended for use with a new East Germany photorepeater, the UER. ^{2/} The UER can be equipped with three lenses with reduction ratios of 1:5, 1:10, or 1:15. Maximum die size is given as 10 mm x 10 mm, and maximum mask size as 125 mm x 125 mm. Minimum feature size claimed (using the 1:15 lens) is 1 μm with reproducible accuracy of $\pm 0.1 \mu\text{m}$. []

25. There seems little reason to doubt that East Germany has developed an E-beam system. In this area, as in the area of data processing computers, East Germany may have acquired valuable technology from West German engineers. We cannot confirm, however, that the ZBA-10 actually meets the specifications claimed for it, or if it operates reliably. Further, communist countries typically advertise a product after an initial prototype is built giving a false impression of availability. And

^{1/} Covered under lithography. See p. 8 below.

^{2/} The East Germans claim to have introduced this model in 1977.

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the lag-time between prototype and factory production in advanced technology often is measured in years. In short, East German claims of the development of an E-beam system should not be taken as prima facie evidence of a production capability. Indeed, recently acquired samples of East German microcircuits, representing current East German state-of-the-art, are of a level of complexity far below what would be expected from equipment with the capabilities claimed by East Germany. []

26. The USSR and other East European communist countries continue to seek Western-made maskmaking equipment. Since 1974, the USSR has acquired such equipment in significant quantities as shown in the tabulation below. Actual deliveries could be larger than shown since our information is not complete. []

Type Equipment

Quantity Acquired
(units)

Pattern compiler
Pattern generator
Digital Plotter
Photorepeater
Contact printer

10
9
11
9
9

27. More recently, the Soviets have shown intense interest in acquiring Western E-beam systems; none are known to have been acquired. A growing number of suppliers, however, increases the chances that the Soviets eventually will successfully acquire a Western E-beam system. []

28. The Soviets have acquired maskmaking equipment and materials also, including mask comparators, master reticle instruments and mask blanks. The latter have been purchased in large quantities. In 1979, for example, a single purchase was for 200,000 ultra flat, high resolution mask blanks for processing 2" - 4" wafers. []

Lithography

29. Lithography constitutes one of the weakest aspects of Soviet microcircuit technology. Despite claims to the contrary, Soviet mask-aligners are not comparable with Western counterparts,

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or even with those made in East Germany, if East German claims can be believed. The Jena Optical Works claims two projection aligner models (the JuB-PM-50 and JuB-PM-80) designed to handle wafer sizes from 50mm to 75mm with minimum line widths of from 3 μ m to 5 μ m. The Jena plant also claims to have developed a wafer stepper (designated the MPUR) which provides minimum line widths of 0.8 μ m to 3 μ m over image field sizes from 6mm x 6mm to 10mm x 10mm; it is said to be capable of handling wafers up to 100mm diameter. ☐

30. Available evidence casts doubt on the East German claims. For example, samples of East German MOS ICs acquired in 1979 revealed minimum line widths of 7 μ m and generally lacked the tight geometries that are well within the capabilities of the lithography equipment described above. Moreover, the East Germans were trying to acquire an older model Western aligner as recently as late 1978 in order to copy its design. ☐

31. Samples of Soviet MOS ICs made in 1978 reflected 5 μ m line widths. It is believed that these devices were fabricated using Western equipment for the key fabrication processes. The USSR has shown a strong preference for Western mask aligners. Since 1973, the USSR has purchased more than 90 Western mask aligners--including contact, proximity, and projection types--and continues to seek new Western models. The Soviets also are trying to acquire wafer steppers. ☐

32. In addition to mask aligners, the USSR has purchased photoresists in large quantities. Soviet-made photoresists are of low quality. Western photoresists play a very important role in Soviet microcircuit production. ☐

Etching

33. The USSR lags behind the West in precision etching technology and equipment. Since 1969, and continuing into the present, the USSR has purchased etching equipment valued in the millions of dollars for a variety of applications including shadow masks, printed circuit boards, and microcircuits. The Soviets have purchased at least 15 complete wet etch processing lines since 1975. These purchases have included a full range of photoresist, water, and etch equipment including; spinners, developers, ovens, scrubbers, D.I. water plumbing and filtering systems, and automatic transporters. More recently, the Soviets have purchased advanced dry etch equipment--plasma etchers and ion milling equipment. It is believed that most Soviet advanced microcircuits are fabricated on Western equipment. ☐

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34. In 1979, the USSR published sketchy information on a plasma etcher of their own design, which is not believed to be in production. Virtually all of plasma etchers that the Soviets have acquired have been purchased since that 1979 announcement.

35. None of the East European countries are known to have developed any dry etch equipment for microcircuit fabrication, or any etching equipment for advanced circuits. East Germany produces wet etch equipment for printed circuit board production, and Bulgaria has recently announced new developments in printed circuit board fabrication equipment.

36. Probably the USSR and East European countries will continue to seek to purchase precision etching equipment from Western suppliers. Such purchases will assume increasing importance as the Communist countries attempt to bring micro-circuit designs down to the 5 μ m level.

Diffusion/Ion Implantation

37. The USSR produces both diffusion furnaces and ion implanters for semiconductor fabrication. Recent model diffusion furnaces are multitube systems with some form of computer control. In addition, the Soviets have developed at least one model ion implanter for industry use.

38. Although Soviet diffusion furnaces have improved significantly over the past five years, with stress on large diameter tubes, longer work zones, and better control of temperature in the work zone, they are less advanced than Western models. In particular, Western models maintain a high level of computer control of individual furnace tubes with monitoring of key performance parameters and built-in diagnostic capabilities. Computer-controlled diffusion furnaces are relatively new in the USSR and probably are not widely available.

39. Some ion implanters were available in the USSR in the early 1970s, but these were laboratory models with features undesirable for semiconductor fabrication. By the mid-1970s the first industrial models were delivered to a few semiconductor plants. According to [redacted] ion-implanters had two major problems as of mid-1977: oil leakage from the forepump and iron release from the implanter during implantation resulting from poor design of the equipment. The current status of ion-implanting equipment is not known.

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40. The USSR has performed extensive research into laser annealing applications for semiconductor fabrication. Although basic research is impressive, there is no evidence of application. Similarly, there is very little information on Soviet development and use of electron beam annealing. []

41. The USSR has purchased Western diffusion furnaces and ion implantation equipment in substantial quantities. Since 1973 the Soviets have purchased up to 250 diffusion furnaces and several ion implanters. There are unconfirmed reports that significant numbers of ion implanters are being sold to the USSR by the [] A few [] ion implanters have been seen in East European semiconductor plants. []

42. East Germany is the main producer of furnaces in Eastern Europe, but little is known of the technical capabilities of German furnaces. Although a few are in use in Eastern Europe, most in use appear to be Soviet-made. East European countries also have purchased Western furnaces. Ion implanters are not known to be produced in Eastern Europe. []

Thin Film Deposition

43. The USSR has been using thin film deposition techniques for many years, starting with thin film hybrid circuits in the early 1960s. The USSR uses two basic deposition techniques-- evaporation and sputtering. The Soviets are less advanced in chemical vapor deposition (CVD) and little is known about Soviet equipment for CVD, or the more recent LPCVD. In Eastern Europe, only East Germany has demonstrated advanced technology in thin film deposition technology. []

44. Soviet-made equipment for thin film deposition is thought to be less advanced than Western deposition technology. However, recent information on Soviet equipment is not available. In the early 1970s, poor Soviet vacuum pumps are known to have caused a considerable number of problems in hybrid circuit production facilities. Evaporators with rated pressures of 1×10^{-6} Torr could not be used beyond 1×10^{-5} Torr, and contamination due to back flow of oil was a constant problem. It is not known if new models of evaporators and sputtering equipment have overcome all of the deficiencies of earlier models. []

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45. The USSR has purchased Western evaporation and sputtering equipment for many years even when improved Soviet models were said to be available. There have been reports that large quantities of evaporators and sputtering systems have been sold throughout Eastern Europe and the USSR.

We can confirm that a few items of equipment which date back to the early 1970s are in use in the USSR.

46. Concerning CVD equipment, only one Western model is known to have been purchased by the USSR. Probably most Soviet CVD work is done in modified diffusion furnaces. Soviet purchases of ultrafine graphite forms, said to be ideally suited for silicon wafer processing, may have been intended for diffusion furnace modifications for CVD. In the next few years the Soviets may step up efforts to acquire CVD and LPCVD equipment as Soviet production shifts increasingly to MOS and more advanced bipolar technologies. It is believed that the USSR is now engaged in development of CVD technological processes, but the application of these processes to large scale industrial production is not imminent.

47. Test, process control, and analytical instrumentation equipment for microcircuit fabrication represent critical weaknesses in Soviet and Eastern European technology. The USSR, East Germany, Hungary, Poland, and Czechoslovakia claim progress in developing advanced microcircuit test equipment, but their claims are highly suspect. Automatic test equipment (ATE) for microcircuit production is high on the shopping lists of all CEMA countries, and most of the microcircuit ATE in use is of Western manufacture.

48. Since 1973, the USSR has purchased at least 26 ATE systems capable of testing LSI devices. Purchases have included probe testers and multiple test stations providing high volume test capacity. As microcircuit technology advances, the USSR will probably need more advanced Western ATE to achieve volume production.

49. Soviet and East European capabilities in process control and analytical instrumentation are poorly developed. A major problem has been the consistent failure of CEMA industries to get advanced instruments out of the laboratory and into production. It seems that many advanced types of

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instruments are developed at scientific facilities, but few are ever manufactured for industrial uses. As a result, users are forced to build their own instruments, or rely on Western models. Moreover, in-house models vary from plant to plant in levels of accuracy. Repeated Soviet efforts to correct this situation have been unavailing, leading to purchases from Western suppliers. ☐

50. Little is known about Soviet capabilities for special categories of package testing--package leak, centrifuges, vibration, temperature cycling, wire-bond pull, x-ray die attach, and radiation sources. Fragmentary information suggests that Soviets continue to use very primitive methods for these types of tests. It is apparent from analysis of many Soviet circuits over the years that very few package tests are performed on Soviet devices. ☐

51. The USSR is known to have purchased Western leak testers, centrifuges, vibration test equipment, and x-ray die attach equipment, but quantities are unknown. Most of these test equipments are especially important to high reliability parts intended for military/space applications. ☐

52. All categories of test equipment are likely to remain a serious deficiency in Soviet and East European microcircuit production in the 1980s. Western equipment can be expected to become increasingly important to the USSR as microcircuits become more complex. ☐

Assembly

53. Automated assembly of microcircuits is not as advanced in the USSR and Eastern Europe as in the West. Although the USSR and East Germany advertise equipment for all stages of microcircuit assembly, none of it is equal to Western models. ☐

54. Recent samples of Soviet 4K and 16K RAMs, although carefully selected to impress Western experts, reveal some specific weaknesses in assembly technology. In addition to major problems related to the use of outdated packages and poorly plated lead frames, one assembly weakness was in the die attach. The Soviet 4K RAM used a conventional Au-Si preform method, which showed a very porous die attach with about 50 percent voiding. However, in die scribing, wire bonding, and other assembly areas, both the 4K and 16K RAMs

[REDACTED] ~~SECRET~~ [REDACTED]
[REDACTED]
were rated as very good. Other recent samples of Soviet microcircuits have tended to show overall improvement in most stages of assembly. Much of this improvement is believed to be the direct result of Soviet acquisitions of Western equipment. [REDACTED]

55. The USSR has acquired significant quantities of Western assembly equipment since the early 1970s, including a complete assembly line for microcircuit devices, believed to have been installed in the late 1970s. In addition, the Soviets have acquired substantial numbers of dicing machines, die bonders, wire bonders, and hermetic sealing units since 1977. These purchases have included both laser and saw scribes, automatic and manual die bonders, a full range of wire bonders from manual to automatic types, and a few beam lead bonders. [REDACTED]
[REDACTED]

56. The USSR is currently having great difficulty in obtaining a good hermetic seal on ceramic packages. Other Soviet packaging problems are only now becoming evident as the USSR moves closer to full scale LSI production. These problems are expected to increase as the USSR shifts more of its product mix to LSI. Microcircuit packaging, in general, does not appear to have been given sufficient emphasis in the USSR. Relatively easy access to Western assembly equipment may have caused the Soviets to neglect this area of development. Unless the USSR continues to enjoy this easy access to Western assembly technology, serious bottlenecks in Soviet LSI and VLSI production may develop over the next several years. [REDACTED]

Facilities

57. Modern plant facilities specially designed for microcircuit fabrication have only recently become common in the USSR. Until the early to mid-1970s, most production was in old industrial plants converted into semiconductor facilities. Many of these converted facilities proved wholly inadequate for semiconductor fabrication, because of their poor environmental controls and their locations near sources of excessive air and water pollution. As recently as 1973, very few Soviet plants had effective water purification systems, and clean areas of class 10,000 or better were rare. A major expansion of microcircuit production facilities began after 1970, and by 1979 sixteen modern plants were at or near completion.

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Ten of these facilities were completed after 1975 and probably conform much more closely to Western standards for micro-circuit fabrication facilities. ()

58. The USSR is known to have obtained from Western sources blueprints for organization of production and layout of equipment for microcircuit fabrication facilities. There is insufficient information about these transactions to judge how efficiently production flow and equipment in current Soviet microcircuit facilities is organized. ()

59. Eastern Europe shared many of the early Soviet problems in semiconductor fabrication facilities. However, as with the USSR, most of the Eastern European countries now have newer facilities better suited to production of microcircuits. Since several of these countries have received assistance from Western firms, many prior deficiencies have probably been corrected. ()

60. The USSR and Eastern European countries are now probably fully aware of the importance of strict adherence to closely controlled environmental conditions in microcircuit fabrication facilities. However, there is insufficient information to conclude that all plants maintain their facilities as required for high quality, high yield microcircuit production. Indeed, available information on yield rates for certain types of microcircuits suggests that very few plants do so. It is possible that the situation is better in plants where Western firms have provided complete facilities and training for particular microcircuits or processes. ()